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Composition and Toughness of some Bodies Suitable for Spark Plugs

Ceramic Engineering

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COMPOSITION AND TOUGHNESS OF SOME BODIES SUITABLE FOR SPARK PLUGS

BY

SILAS CARL LINBARGER
AND
LOREN CUSHING BOW

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CERAMIC ENGINEERING

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IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Ceramic Engineering

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COMPOSITION AND TOUGHNESS OF SOME BODIES SUITABLE FOR SPARK PLUGS

INTRODUCTION

The wide-spread adoption of the internal combustion engine has created a demand for a peculiarly tough porcelain suitable for the insulating portion of spark plugs.

A spark plug porcelain is subjected to a high pressure during the explosion in the cylinder and to a comparatively large temperature fluctuation. The stress due to explosion is compressive in the longitudinal direction and practically any porcelain body, if well made and provided with a shoulder of sufficient thickness, will withstand such stress. In the common grades of spark plugs on the market the sudden heating and cooling and the uneven heating longitudinally which the porcelain undergoes, cause cracks which ultimately permit a short circuit in the plug. This is known as fire-cracking and is the source of much of the trouble encountered in the manipulation of gas engines. It is especially troublesome in air cooled and Marine engines where the porcelain reaches a high temperature within the cylinder and is subjected to a blast of air and frequently to a spray of water on the exposed portions.

It was attempted in this investigation to produce a porcelain of such increased toughness and resistance to sudden temperature changes that it might successfully withstand the most severe working conditions.

The manufacturers of spark plugs maintain secrecy as to the composition of their porcelains. Consequently, the writers were unable to find any data relative to the composition, manufacture or tests of spark plug porcelains. The German Bosch standard spark plug is considered by unprejudiced and experienced dealers and owners

[illegible]

[illegible]

of automobiles, motor boats and accessories as the best plug on the market. It has attained this leadership through its resistance to fire cracking, its long life and its ability to withstand hard usage. Chemical analysis of one of these porcelains showed a content of MgO[1] which may account for its toughness.

In attempting to find a body that would make a more permanent pyrometer tube, Montgomery[2] investigated a series of porcelain mixtures in which fused Magnesite was used. He concluded that MgO gives high thermal conductivity and low coefficient of expansion. His results showed that bodies containing from 15% to 50% MgO possessed a marked amount of toughness and were surprisingly resistant to temperature changes. This verified the results of Clare[3] who successfully used MgO in the production of a refractory ring for gas mantles.

Bell[4] studied the effect of Al_2O_3 on the toughness of a porcelain body designed for chemical ware and resistance to sudden temperature changes. He concludes that the burned body should have as low a coefficient of expansion as possible, that the nature of the raw materials employed influence the toughness, that the con-

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[1] Analysis of a Bosch plug by the writers, see page 3.

[2] E. T. Montgomery "The Development of Special Refractory Bodies." Trans. Am. Cer. Soc. Volume, XV, 1913, pp. 606.

[3] R. Linn Clare "A Refractory Ring for Inverted Gas Mantles." Trans. Am. Cer. Soc. Volume XIV, 1912, pp. 407.

[4] Llewellyn Bell "Fireproof Porcelains." Trans. Am. Cer. Soc. Volume IX, 1907, pp. 637.

tent of lime should be low, and that there should be some free silica present. No bodies that he produces, however, could compare in toughness with those of Montgomery and Clare which contained MgO.

Previous investigators paid no attention to the relative porosity of the various bodies which they tested, some being thoroughly vitrified while others had a relatively high absorption.

In the present investigation it was decided to prepare a number of porcelain bodies containing MgO, covering a field of composition and to burn each body to such a temperature as would give to all practically the same degree of vitrification.

EXPERIMENTAL WORK

A chemical analysis was made of porcelain from a Bosch spark plug, following the method of analysis given by J. W. Mellor[5]. In the preparation of the porcelain for analysis, the glaze was ground off with an emery wheel. The porcelain body was then ground roughly in an iron mortar and to extreme fineness in agate. A powerful magnet was used to remove any iron which might have been introduced during grinding.

The analysis is as follows:

SiO_2 --------------- 65.11%

Al_2O_3 -------------- 22.03%

CaO --------------- 1.12%

MgO --------------- 9.80%

Alkalies ---------- 1.94% (By difference)

---

[5] J. W. Mellor "A Treatise on Quantitative Inorganic Analysis."

The following empirical formula, calculated from the above analysis, was taken as the basis for Group I.

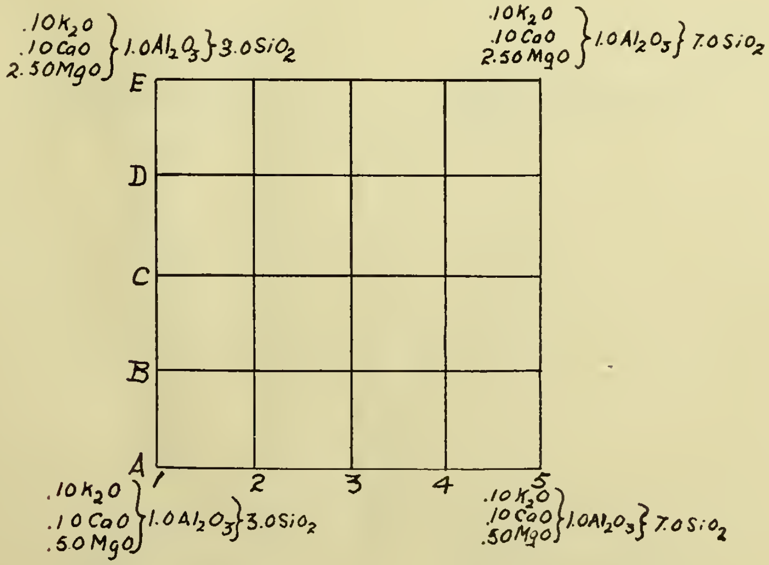
$$\left.\begin{array}{r} .101\ K_2O \\ .150\ CaO \\ 1.22\ \ MgO \end{array}\right)\ 1.0\ Al_2O_3\ \Big)\ 5.8\ SiO_2.$$

From the batch weights given by Montgomery[6] in his work on porcelains, the following empirical formula of the best body which he obtained was taken as the bases of Group II.

$$1.13\ MgO\ )\ 1.0\ Al_2O_3\ )\ 2.0\ SiO_2.$$

Group I included 25 bodies and covered the following field of composition, variations in the MgO and SiO_2 contents being made.

$$\left.\begin{array}{r} .100\ K_2O \\ .100\ CaO \\ .5\text{-}2.5\ \ MgO \end{array}\right)\ 1.0\ Al_2O_3 \cdot\ 3.0\text{-}7.0\ SiO_2.$$



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[6] See page 2.

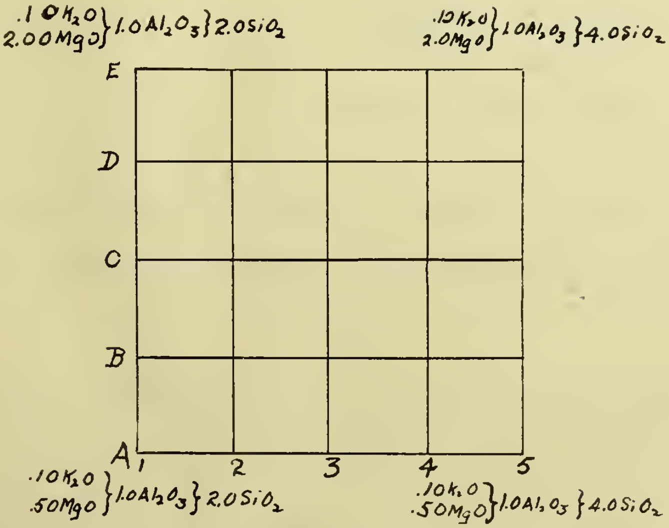
Batch Weights of Group I.

	A-1	A-5	E-1	E-5
Spar	55.6	55.6	55.6	55.6
Kaolin, N. C. ..	116.1	116.1	116.1	116.1
Flint	36.0	276.0	36.0	276.0
$MgCO_3$	42.0	42.0	210.0	210.0
$CaCO_3$	10.0	10.0	10.0	10.0
Tenn. Ball Clay No. 7.	116.1	116.1	116.1	116.1

GROUP II.

In this group a variation in magnesia and silica was made and CaO was excluded. It included 25 bodies outlined on a rectangular diagram and covered the following field:

$$\left.\begin{array}{rl} .1 & K_2O \\ .5\text{-}2.0 & MgO \end{array}\right)\ 1.0\ Al_2O_3\ )\ 2.0\text{-}4.0\ SiO_2.$$


.10 K₂O 2.00 MgO } 1.0 Al₂O₃ } 2.0 SiO₂
.10 K₂O 2.0 MgO } 1.0 Al₂O₃ } 4.0 SiO₂
E
D
C
B
A
1
2
3
4
5
.10 K₂O .50 MgO } 1.0 Al₂O₃ } 2.0 SiO₂
.10 K₂O .50 MgO } 1.0 Al₂O₃ } 4.0 SiO₂

Batch Weights of Group II.

	A-1	A-5	E-1	E-5
Spar	55.6	55.6	55.6	55.6
Tenn. Ball Clay #7 ..	90.3	116.1	90.3	116.1
N. C. Kaolin	90.3	116.1	90.3	116.1
MgO (Fused)	20.0	20.0	100.0	100.0
$Al_2(OH)_6$	31.2		31.2	
Flint		96.0		96.0

MATERIALS.- It was decided to use exclusively American raw materials in this investigation. The following were the ingredients of Groups I and II.

Potash Feldspar :---------------"Brandywine Summit," Pa.

Flint:------------------------- Ohio eight-hour grind.

Clays :------------------------ 1. Tennessee Ball Clay No. 7.

2. North Carolina Kaolin.

Magnesia :--------------------- 1. Fused Magnesite, ground to pass 80 mesh.

2. Magnesium Carbonate, finely ground.

Alumina :---------------------- Aluminum Hydroxide, $Al_2(OH)_6$

The clay content of all bodies in both Groups was made up of equal parts of North Carolina Kaolin and Tennessee Ball Clay No. 7.

In Group I the Magnesia was added as $MgCO_3$ while in Group II it was added in the form of fused Magnesite MgO.

PREPARATION.- The batch weights of the corner bodies of the group were calculated from their formulae and a sufficient

quantity of each was prepared to make the intermediate bodies by blending.

The dry materials were weighed, ground dry for twelve hours and screened through an 80 mesh sieve. The intermediate mixtures were then made by blending these in the proportions given in the tables. Each mixture was placed in a ball mill with sufficient water to make a slip and allowed to thoroughly mix (wet) for three hours. After this the slips were poured into plaster molds lined with cheese cloth and left until a stiff mud consistency was reached. The bodies were then thoroughly wedged, wrapped in cheese cloth, properly labelled and allowed to age in a moist chamber for two weeks, after which they were again thoroughly wedged and molded into test pieces by means of a small Piston Briquett Machine. A column one-half inch in diameter was forced through a circular die and the column was wire cut into trial pieces four inches long. These were marked and placed in a steam heated dryer for 48 hours. The diameter of the pieces was made approximately that of spark plugs just below the shoulder where failure generally occurs.

BURNING.- In order to obtain the proper burning temperature for each body a trial burn was made in a coal fired test kiln of the Ceramic department of the University of Illinois. The trial pieces were packed in clean white Ottawa sand in a compartment so that one piece of each body could be drawn out at any desired temperature. The points at which draws were to be made were determined by Seger cones placed near the center of the compartments. At cones 8, 10, 11, 12, 13 and 14 draws were made and the pieces placed in saggers containing sand.

Absorption determinations were made on the burned pieces according to the usual method. The burning temperature at which the trials showed an absorption of less than four percent was used in the final burning of the test pieces.

The test pieces were laid in clean white Ottawa sand and burned in covered saggers. The bodies maturing at cone 10 were burned in a round, down draft, open fire, kiln burning fuel oil. The remaining bodies were burned to their proper temperatures in the coal fired kiln. The maturing temperatures were again determined by Seger cones placed as near the center of the setting as possible. The duration of the burns varied from twenty eight to forty hours depending upon conditions. The loss incurred in burning was negligible as the pieces did not crack or break and there were but few that showed warpage. All trials that showed any flaws whatsoever were rejected.

TESTING.- From private data obtained from the experimental department of the Cadillac Motor Car Company, Detroit, Michigan, the temperature attained by a spark plug in a running Motor was found to be about 235°C. The following tests were then devised to determine the relative resistance of the different bodies to sudden temperature changes.

Ten pieces of each of the fifty bodies were placed in round saggers and put in a small gas fired muffle kiln and the temperature raised to 400°C for thirty minutes to insure the thorough heating of the test pieces. The wicket was then opened, the saggers quickly removed and their contents plunged into a tank of water at a temperature of 20°C. The pieces which did not crack were replaced

in the saggers and the process repeated for five times. The results are shown in the accompanying diagram.

The temperature of the muffle was then raised to 500°C and similar tests repeated five times with the results shown in the table. These tests did not prove to be severe enough to compare the resistance of the bodies, although the temperature used was 100° higher than the temperature to which the porcelain is subjected in a gas engine.

In order to get comparative results between the various members of the Groups under consideration, a more severe test was devised as follows:

The trial pieces of each body were heated before the flame of a blast lamp, the flame being regulated so as to give a non-luminous flame about six inches long. At the tip of the flame a fire brick was placed in such a manner that it would heat one-half of a test piece placed on the brick, to almost a white heat in one and one-half minutes. The piece was then removed with a pair of crucible tongs and completely immersed in a tank of water kept at 16°C. The trial piece was kept in motion to prevent the formation of a film of steam which would retard its cooling. After cooling to the temperature of the liquid, the piece was taken out and carefully examined for cracks. If microscopic cracks were present the piece would break under a slight strain. If the body showed no cracks or did not break when subjected to a transverse stress, it was again heated and the same process repeated until flaws could be ascertained. The results of these tests are shown in the following table.

In the accompanying diagram lines have been drawn to indicate the compositions showing equal resistance to the last.

GROUP I.

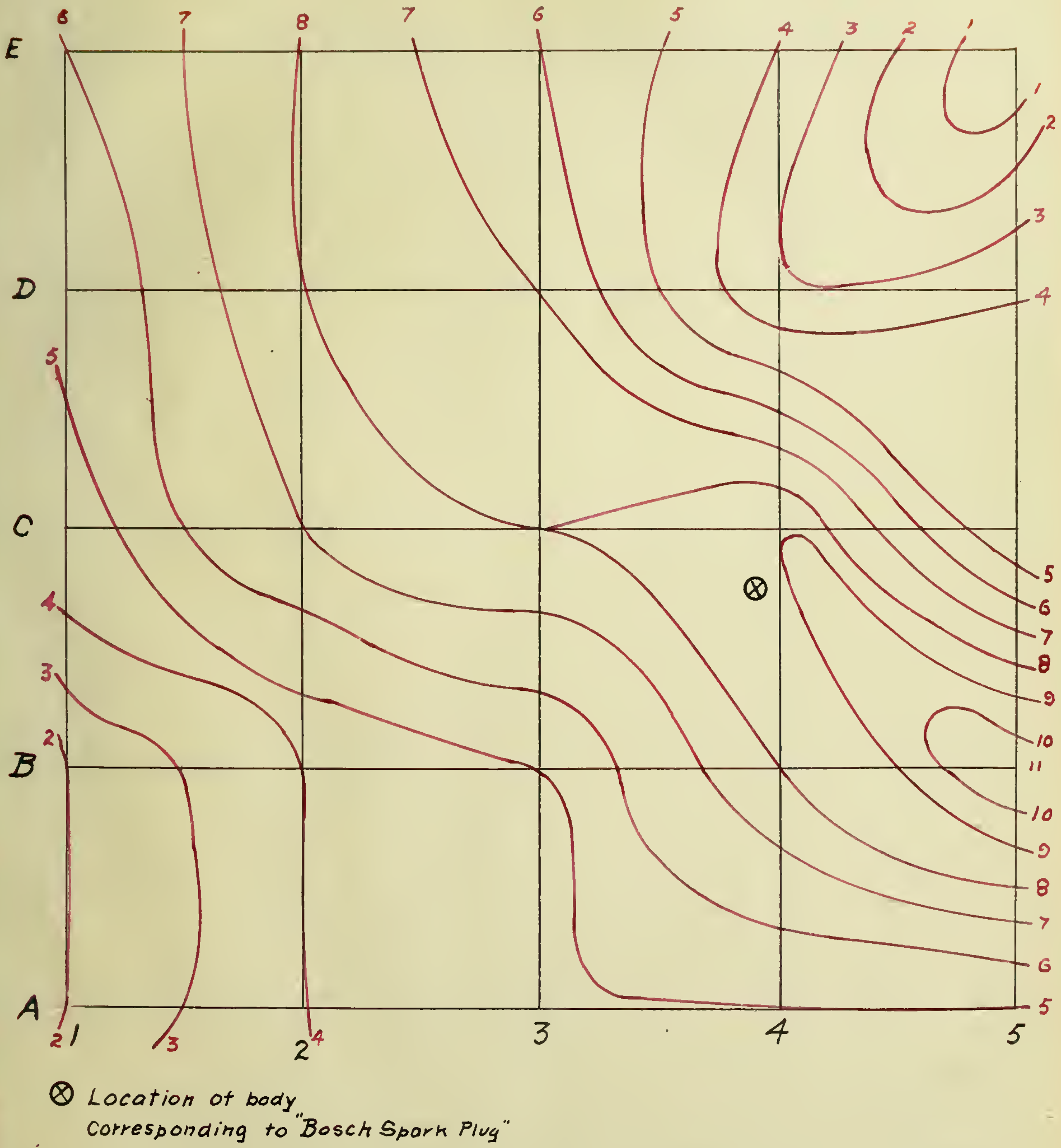
No. of Body	Burning Temp. in Cones.	Number of Tests Each Withstood.		
		400°C	500°C	White Hot.
A-1	10	0	----	2
A-2	10	A 11	A 11	4
A-3	10	"	"	5
A-4	10	"	"	5
A-5	10	"	"	5
B-1	10	"	"	2
B-2	10	"	"	4
B-3	11	"	"	5
B-4	11	"	"	8
B-5	11	"	"	11
C-1	11	"	"	5
C-2	11	"	"	7
C-3	11	"	"	8
C-4	11	"	"	9
C-5	11	2	----	4
D-1	11	A 11	A 11	5
D-2	11	"	"	8
D-3	11	"	"	7
D-4	11	2	1	3
D-5	12	A 11	A 11	4
E-1	12	"	"	6
E-2	12	"	"	8
E-3	12	"	"	6
E-4	12	3	----	4
E-5	12	2	----	0

GROUP II.

No. of Body.	Burning Temp. in Cones.	Number of Tests Each Withstood.		
		400°C	500°C	White Hot.
A-1	13	3	----	2
A-2	13	0	----	1
A-3	13	0	----	2
A-4	13	2	----	3
A-5	13	All	All	2
B-1	13	"	"	4
B-2	13	"	"	4
B-3	14	"	"	1
B-4	14	0	----	2
B-5	14	0	----	4
C-1	14	All	All	8
C-2	14	"	"	6
C-3	14	"	"	6
C-4	14	"	"	7
C-5	14	"	"	8
D-1	14	"	"	5
D-2	14	3	----	4
D-3	14	All	All	5
D-4	14	"	"	4
D-5	14	"	"	4
E-1	14	"	"	4
E-2	14	"	"	5
E-3	14	"	"	3
E-4	13	----	----	-
E-5	13	----	----	-

GROUP ONE

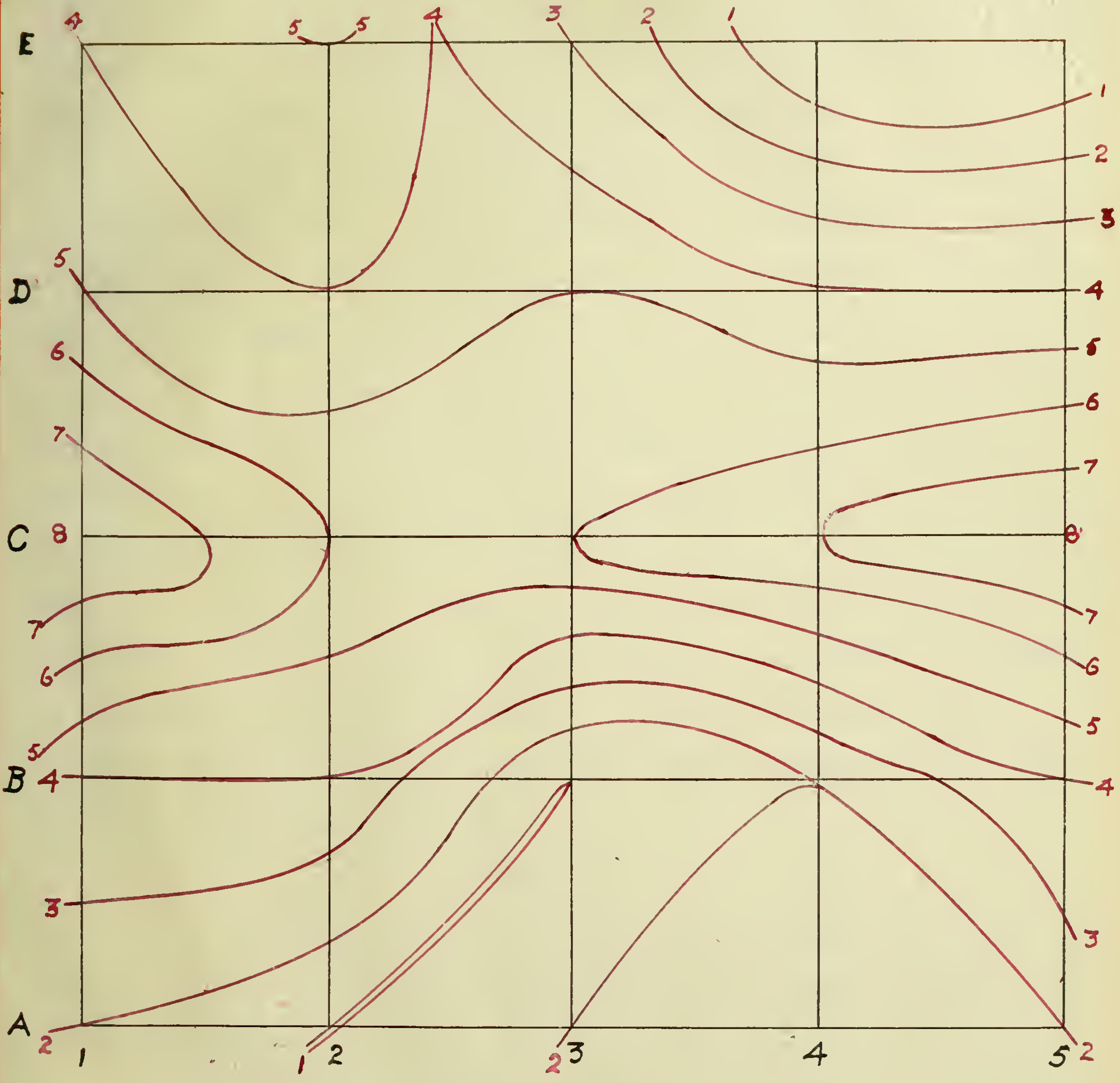
Diagram of Results of "White Heat" Tests.



Red lines pass through bodies of equal toughness and the figures indicate the number of "white heat" tests they withstood.

GROUP TWO

Diagram of Results of "White Heat" Tests.



Red lines pass through bodies of equal toughness and the figures indicate the number of "white heat" tests they withstood.

RESULTS

The character of the breaks developed by these two methods of testing was quite different. When the whole piece was heated to 400 and 500° C, the breaks caused by dipping in the water, were generally in a plane perpendicular to the long axis of the test piece. No chipping or breaking of edges was noted.

The second testing method was far more severe than the first and hence gave a better comparison of the bodies. The breaks in this test were quite varied, some pieces breaking across the long axis of the piece, others chipping off nearly parallel to the axis.

As a whole Group I proved to be the tougher, withstanding more tests and resembling more nearly a body of commercial properties. It was noticed that the bodies which required several heatings and coolings in order to break them in this test, lost their ring before they finally broke, this indicating that invisible cracks must have existed before the final break. No perceptible decrease in strength was noticed, however. Two porcelain cores from American made Spark Plugs, were given the "white-heat" test and broke at the second quenching.

SUMMARY

With an increase of Magnesia a tendency to brown color was noticed in both Groups more especially in Group II where the fused MgO was used.

The best working properties were found in the bodies situated in the middle of the fields of both Groups. The best bodies obtained in Group I are as follows, the most promising composition lying between B_4 and C_4.

Formula. Batch Weights.

(C$_2$) $$\left.\begin{array}{ll} .1 & K_2O \\ .1 & CaO \\ 1.5 & MgO \end{array}\right)\ 1.0\ Al_2O_3\ )\ 4.0\ SiO_2.$$

Spar	55.6
Ball Clay	116.1
N. C. Kaolin	116.1
$CaCO_3$	10.0
Flint	96.0
$MgCO_3$	126.0

(C$_3$) $$\left.\begin{array}{ll} .1 & K_2O \\ .1 & CaO \\ 1.5 & MgO \end{array}\right)\ 1.0\ Al_2O_3\ )\ 5.0\ SiO_2.$$

Spar	55.6
Ball Clay	116.1
N. C. Kaolin	116.1
$CaCO_3$	10.0
Flint	156.0
$MgCO_3$	126.0

(C$_4$) $$\left.\begin{array}{ll} .1 & K_2O \\ .1 & CaO \\ 1.5 & MgO \end{array}\right)\ 1.0\ Al_2O_3\ )\ 6.0\ SiO_2.$$

Spar	55.6
Ball Clay	116.1
N. C. Kaolin	116.1
$CaCO_3$	10.0
Flint	216
$MgCO_3$	126

(B$_4$) $$\left.\begin{array}{ll} .1 & K_2O \\ .1 & CaO \\ 1.0 & MgO \end{array}\right)\ 1.0\ Al_2O_3\ )\ 6.0\ SiO_2.$$

Spar	55.6
Ball Clay	116.1
N. C. Kaolin	116.1
$CaCO_3$	10.0
Flint	216
$MgCO_3$	84

(B$_5$) $$\left.\begin{array}{ll} .1 & K_2O \\ .1 & CaO \\ 1.0 & MgO \end{array}\right)\ 1.0\ Al_2O_3\ )\ 7.0\ SiO_2.$$

Spar	55.6
Ball Clay	116.1
N. C. Kaolin	116.1
$CaCO_3$	10
Flint	276
$MgCO_3$	84

In Group II the results were more erratic but the best bodies appeared to be those of series C, numbers 1 to 5 inclusive. A eutectic seems to exist near E_4 and E_5 as these bodies fused in burning to Cone 14.

The best bodies obtained in Group II are as follows:

	Formula.	Batch Weights.	
(C_1)	$\left.\begin{matrix}.1\ K_2O\\1.25\ MgO\end{matrix}\right) 1.0\ Al_2O_3)\ 2\ SiO_2.$	Spar	55.6
		Ball Clay	90.3
		N. C. Kaolin	90.3
		MgO	60
		$Al_2(OH)_6$	31.2
(C_2)	$\left.\begin{matrix}.1\ K_2O\\1.25\ MgO\end{matrix}\right) 1.0\ Al_2O_3) 2.5\ SiO_2.$	Spar	55.6
		Ball Clay	96.75
		N. C. Kaolin	96.75
		MgO	60
		$Al_2(OH)_6$	23.4
		Flint	24
(C_3)	$\left.\begin{matrix}.1\ K_2O\\1.25\ MgO\end{matrix}\right) 1.0\ Al_2O_3) 3.0\ SiO_2.$	Spar	55.6
		Ball Clay	103.2
		N. C. Kaolin	103.2
		MgO	60
		$Al_2(OH)_6$	15.6
		Flint	48
(C_4)	$\left.\begin{matrix}.1\ K_2O\\1.25\ MgO\end{matrix}\right) 1.0\ Al_2O_3)\ 3.5\ SiO_2.$	Spar	55.6
		Ball Clay	109.65
		N. C. Kaolin	109.65
		MgO	60
		$Al_2(OH)_6$	7.8
		Flint	72.0
(C_5)	$\left.\begin{matrix}.1\ K_2O\\1.25\ MgO\end{matrix}\right) 1.0\ Al_2O_3) 4.0\ SiO_2.$	Spar	55.6
		Ball Clay	109.65
		N. C. Kaolin	109.65
		MgO	60
		Flint	96

All the body compositions given above showed excellent working properties and burned to a white dense body.

CONCLUSION.

The mixtures containing lime produced tougher bodies than those in which lime was absent. We may therefore conclude that lime in the presence of Magnesia imparts toughness to a porcelain body, possibly due to the formation of complex Calcium Magnesium Silicate which has a low coefficient of expansion.

In the fields under investigation low Magnesia and high Silica; and high Magnesia and low Silica produced tough bodies. High Magnesia and high Silica gave weak bodies, possibly due to the fact that Silica and Magnesia were both in excess and combined to form a crystalline Magnesium Silicate.

In the bodies in which Magnesium Carbonate was used tougher bodies were produced than those in which fused Magnesite was used. This is accounted for by the fact that the $MgCO_3$ was finer ground than the MgO. Consequently the bodies containing MgO lacked homogeneity.

The failure of the Spark Plug porcelain of American manufacture indicates that the compositions are not suitable for the conditions to which the porcelain is subjected. As far as can be learned, it is a general practice among American manufacturers to employ the same body composition that they use in the manufacture of their high tension porcelain insolators. While it is true that porcelains for electrical purposes show high di-electric strength, a property not essential in Spark Plugs, they are not adapted to withstand the sudden temperature changes whidh are required in gas engine practice.

For a durable porcelain for Spark Plugs, the writers recommend the use of a body similar to the following composition.

FORMULA

$$\left.\begin{array}{r} .1\ K_2O \\ .1\ CaO \\ 1.0\ MgO \end{array}\right\}\ 1.0\ Al_2O_3\ )\ 7.0\ SiO_2\ .$$

WEIGHTS

Spar	55.6
Ball Clay	116.1
Kaolin	116.1
CaCo	10.0
Flint	276.0
$MgCO_3$	84.0

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